Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Artificial Materials applied to planar antenna

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Biography

Dorsaf Omri received the Master degree in Mathematics from Faculty of Mathematical, Physical and Natural Sciences of Tunis and the MSc degree in Communication technologies from the National Engineering School of Tunis.

In 2010, she received the PhD degree in Information and Communication Technologies and Sciences from the National Engineering School of Tunis.

Her research interest is in the field of electromagnetic modeling and time domain numerical methods.

Abstract

Ameliorate the performance of planar antenna is the object of many research works to allow their integration in the telecommunication systems. In recent years, Metamaterials or composite artificial materials have attracted a lot of interest in many applications particularly the miniaturization of antenna.

Metamaterials are materials of non-natural properties, introduced by Pendry, in 2000. In fact, there are various types of metamaterials: materials with a negative permittivity and permeability called “left-handed” or “negative refractive index”, materials of infinite impedance, material with high permeability…

In this work, we use two artificial materials:

1. The artificial material of high permeability to miniaturize a planar antenna. The structure of this material is composed of a substrate and a Split Ring Resonator (SRR)
2. The material with a negative permittivity and permeability to ameliorate the directivity of a planar antenna. The structure of this material is composed of a substrate, a Split Ring Resonator (SRR) and a wire.

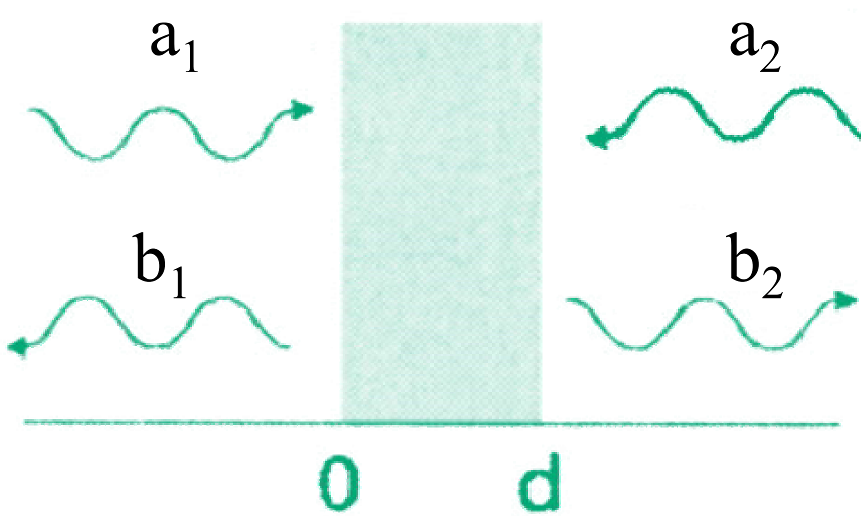
Keywords: *Directivity, High permeability, Metamaterial, Miniaturization, Planar antenna, Negative-index, SRR, Wire.*

Effective parameters characterizing the artificial material

Application of the homogenization procedure to replace the parameters of the periodic artificial material by a material characterized by an effective permittivity and permeability.

Transmission-reflection on a material of thickness d and of effective parameters ε_{eff} and μ_{eff}

Effective parameters characterizing the artificial material



Transfert Matrix **T**

$$\begin{pmatrix} a_2 \\ b_2 \end{pmatrix} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ b_1 \end{pmatrix}$$

Matrix **S**

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

Material with index n and thickness d:

$$\begin{pmatrix} \vec{E}(z+d) \\ \vec{H}(z+d) \end{pmatrix} = T \begin{pmatrix} \vec{E}(z) \\ \vec{H}(z) \end{pmatrix} \Longrightarrow T = \begin{pmatrix} \cos(nkd) & -\frac{z}{k}\sin(nkd) \\ \frac{k}{z}\sin(nkd) & \cos(nkd) \end{pmatrix}$$

Effective parameters characterizing the artificial material

Matrix S

$$S_{11} = r = \frac{\frac{1}{2}\left(\frac{T_{21}}{ik} - ikT_{12}\right)}{T_s - \frac{i}{2}\left(ikT_{12} + \frac{T_{21}}{ik}\right)} = \frac{i}{2}\left(\frac{1}{z} - z\right)\sin(nkd)$$

$$S_{12} = t = \frac{1}{T_s + \frac{1}{2}\left(ikT_{12} + \frac{T_{21}}{ik}\right)} = \frac{1}{\cos(nkd) - \frac{i}{2}\left(z + \frac{1}{z}\right)\sin(nkd)}$$

$$S_{21} = t = \frac{1}{T_s + \frac{1}{2}\left(ikT_{12} + \frac{T_{21}}{ik}\right)} = \frac{1}{\cos(nkd) - \frac{i}{2}\left(z + \frac{1}{z}\right)\sin(nkd)}$$

$$S_{22} = r = \frac{\frac{1}{2}\left(\frac{T_{21}}{ik} - ikT_{12}\right)}{T_s - \frac{i}{2}\left(ikT_{12} + \frac{T_{21}}{ik}\right)} = \frac{i}{2}\left(\frac{1}{z} - z\right)\sin(nkd)$$

$$T_{11} = T_{22} = T_s$$

Effective parameters characterizing the artificial material

Effective index

$$n_{eff} = \frac{1}{kd}\arccos\left(\frac{1-r^2+t^2}{2t}\right)$$

Effective impedance

$$Z_{eff} = \sqrt{\frac{(1+r^2)-t^2}{(1-r^2)-t^2}}$$

Effective permeability

$$\mu_{eff} = nz = \left(\frac{\arccos\left(1-r^2+t^2 \big/ 2t\right)}{kd}\right)\left(\sqrt{\frac{(1+r^2)-t^2}{(1-r^2)-t^2}}\right) = \mu' + i\mu''$$

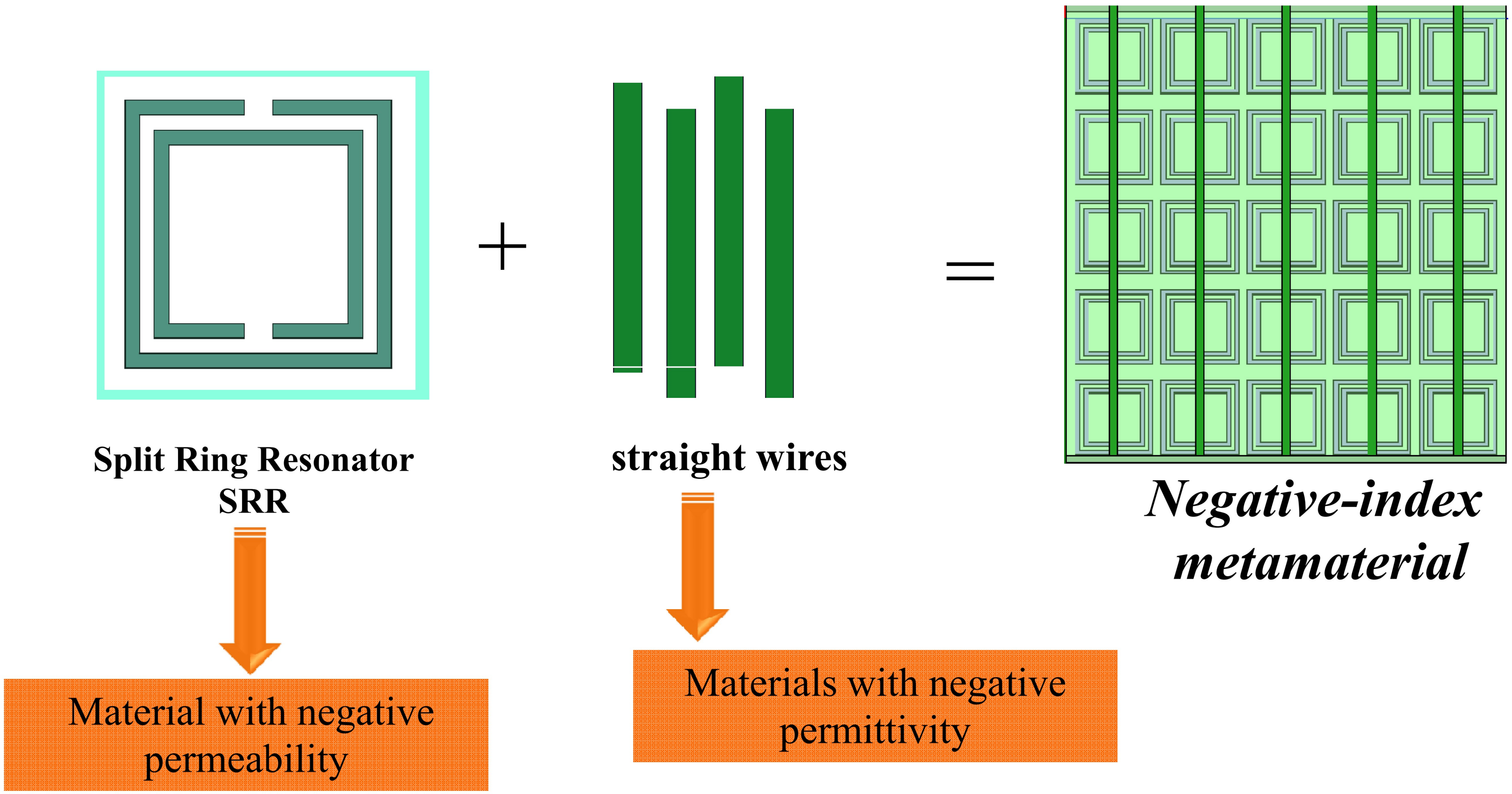
Effective permittivity

$$\varepsilon_{eff} = \frac{n}{Z} = \frac{ar\cos\left(1-r^2+t^2 \big/ 2t\right)}{kd} \Bigg/ \sqrt{\frac{(1+r^2)-t^2}{(1-r^2)-t^2}}$$

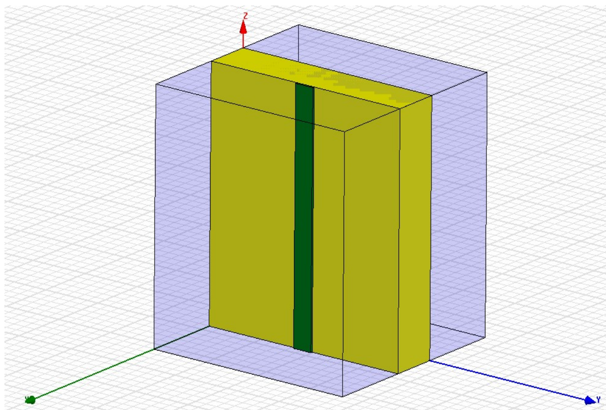
r: the reflection coefficient
t: the transmission coefficient

d: the thickness of material
k : the wave number

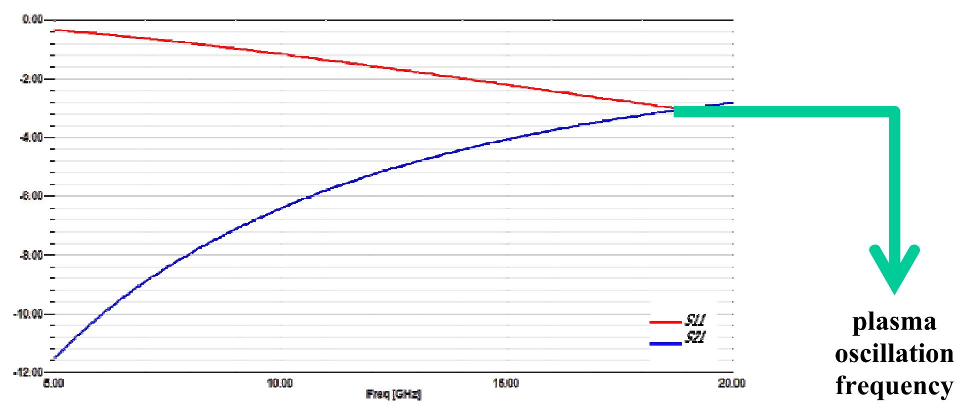
Negative-index metamaterial

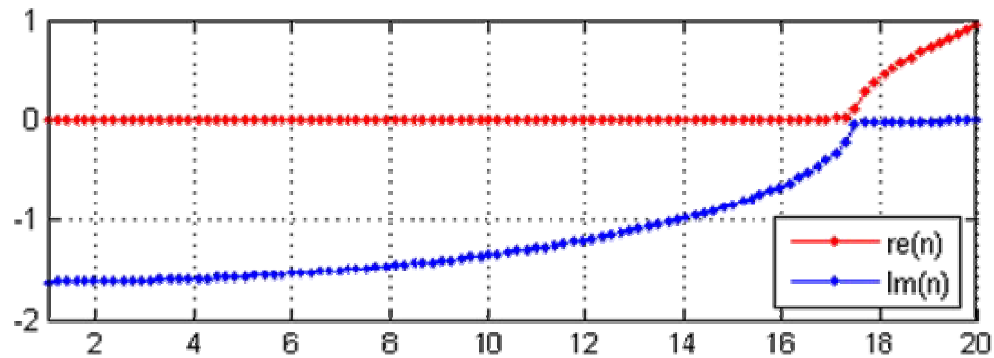


Negative-index metamaterial



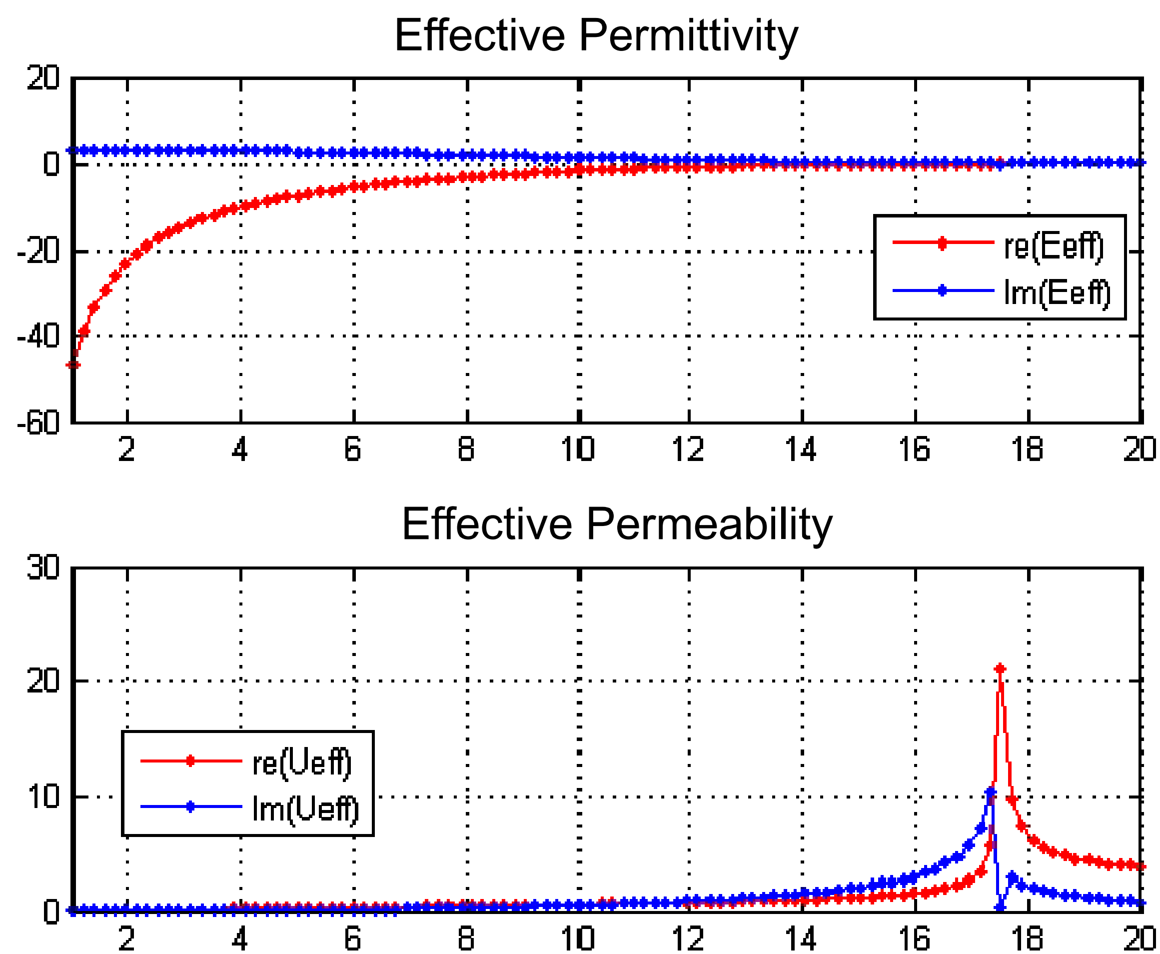
Straight wire



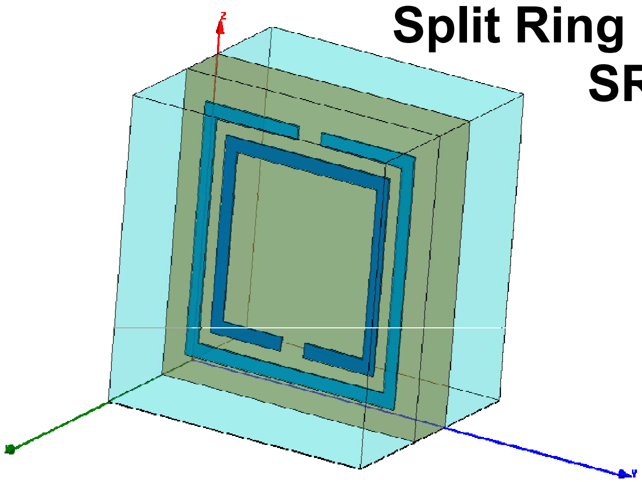


Negative-index metamaterial

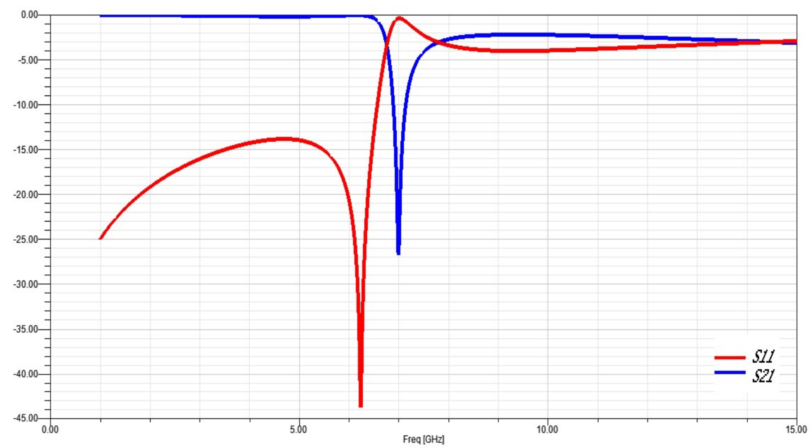
Effective parameters characterizing the straight wire



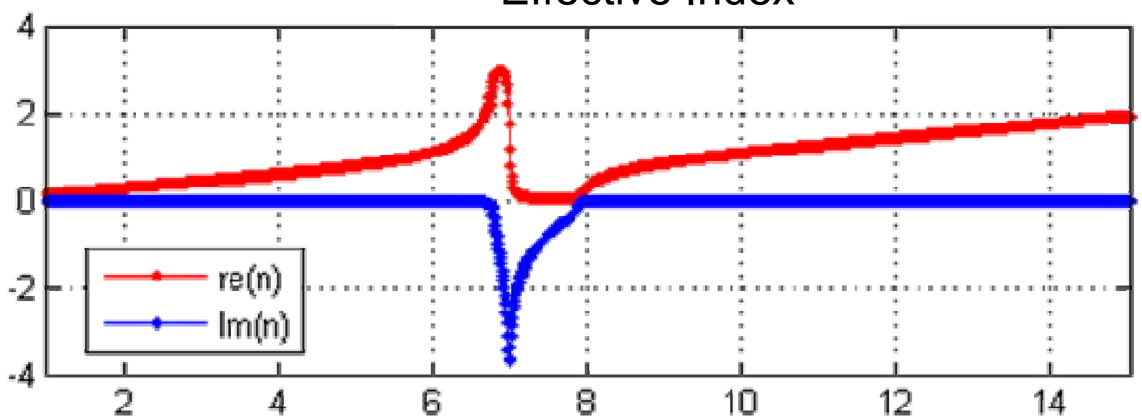
Negative-index metamaterial



Split Ring Resonator
SRR

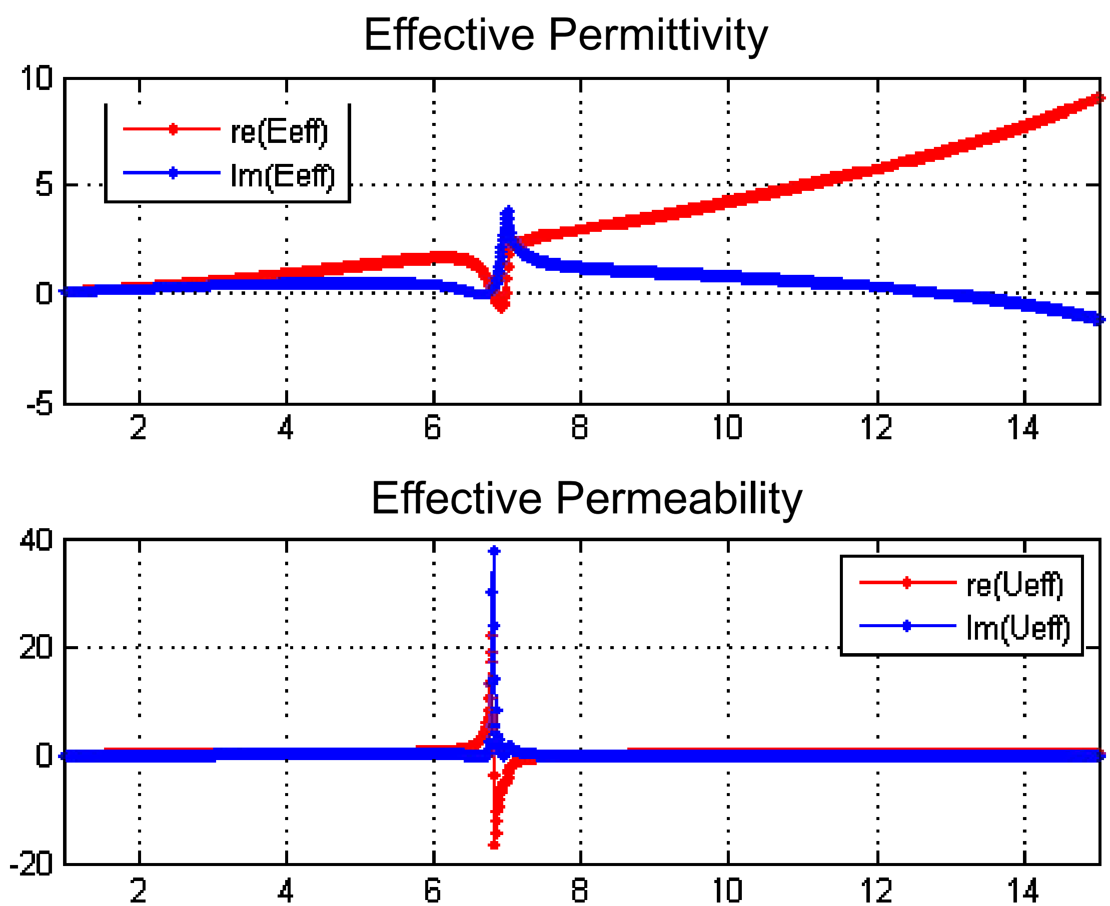


Effective Index



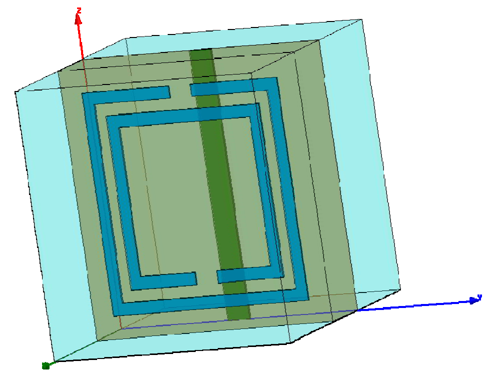
Negative-index metamaterial

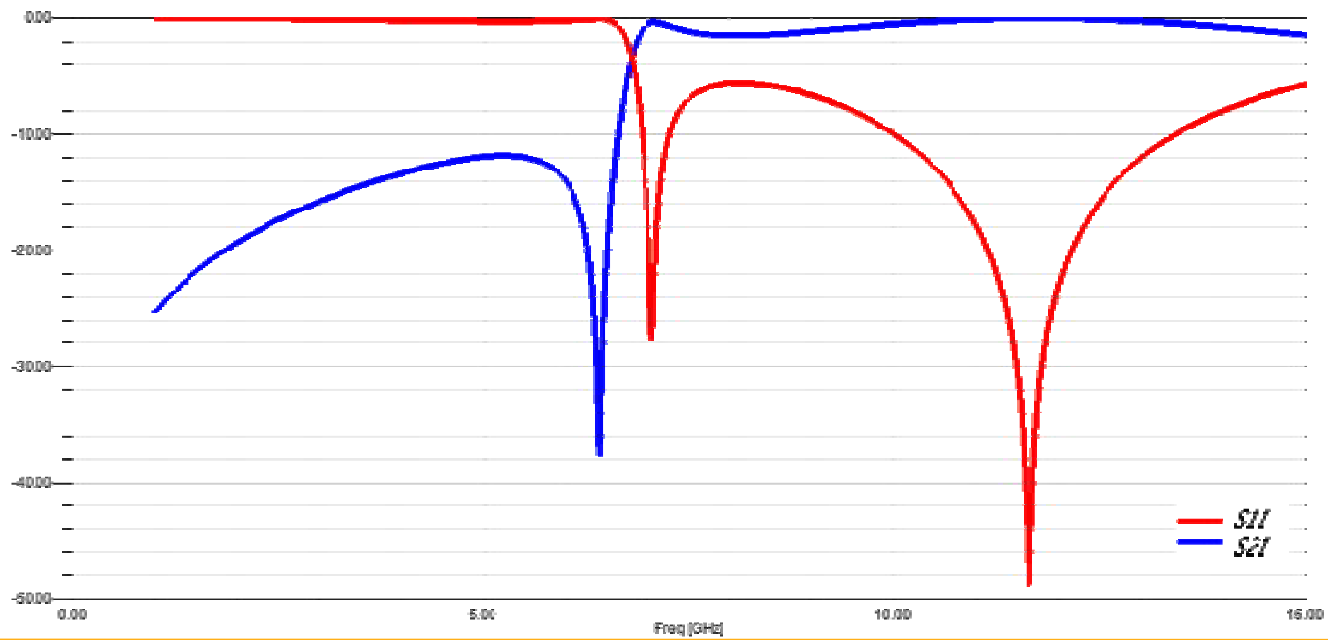
Effective parameters characterizing the SRR



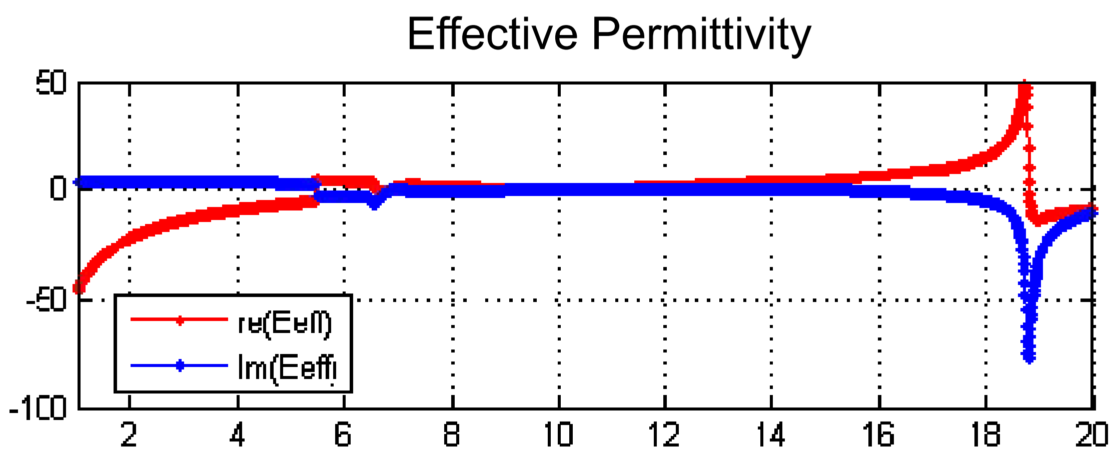
Negative-index metamaterial

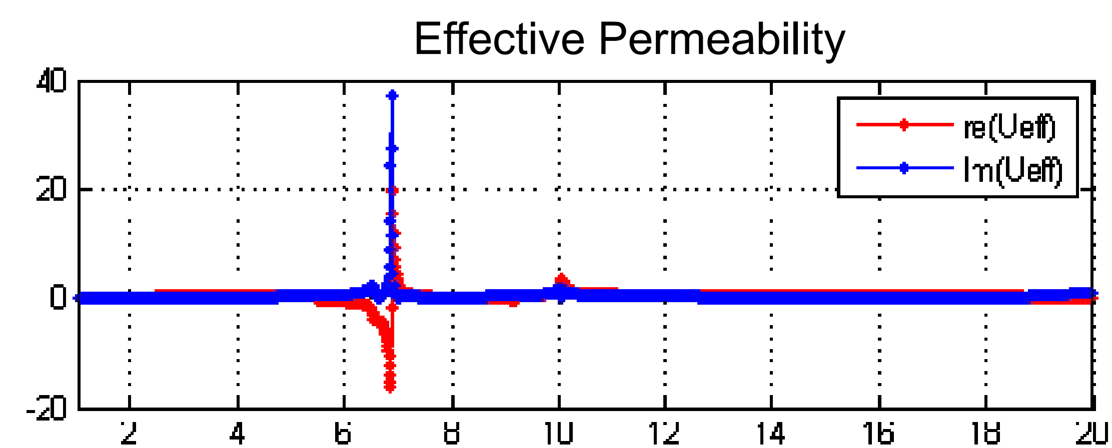
Association of SRR and wire





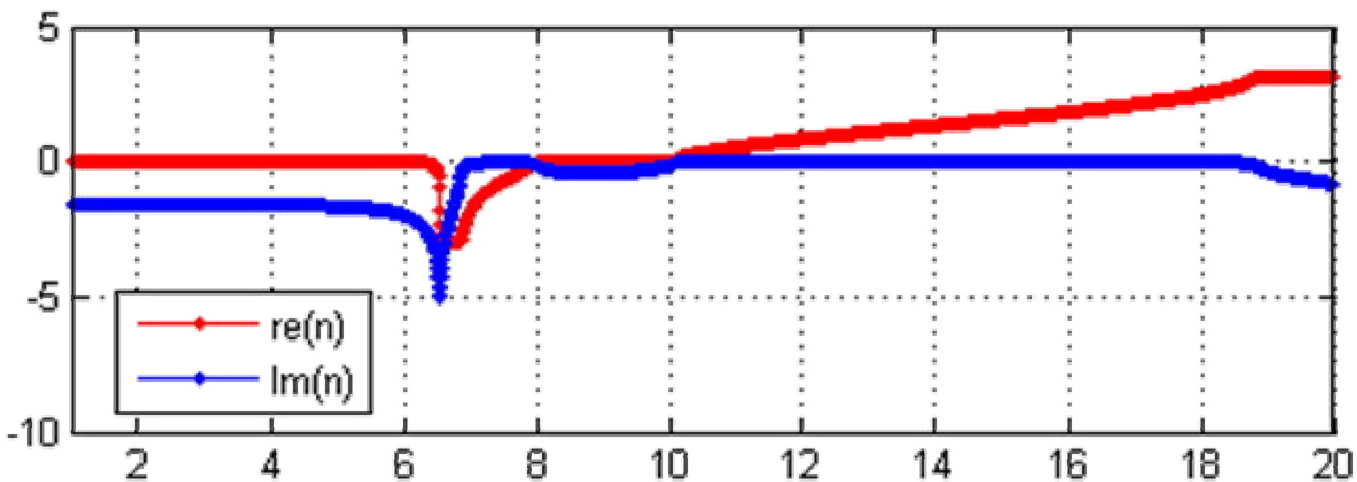
Negative-index metamaterial



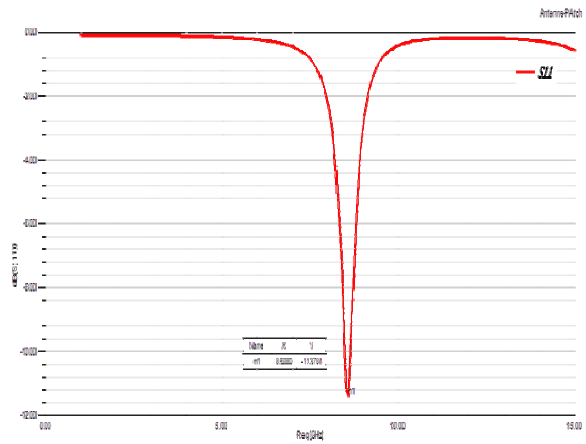


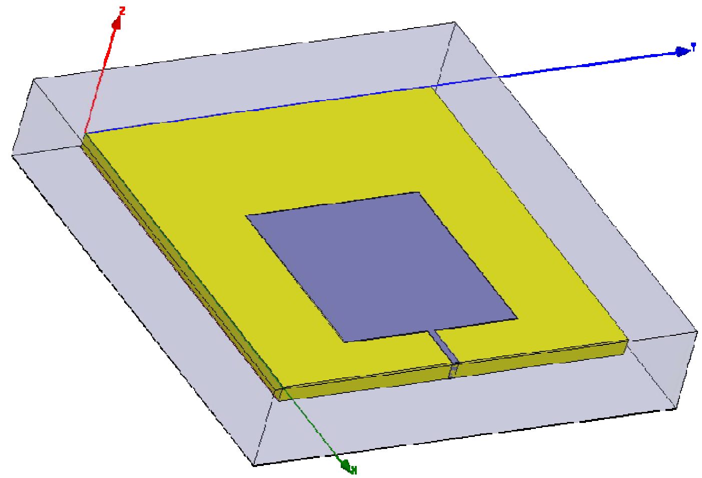
Negative-index metamaterial

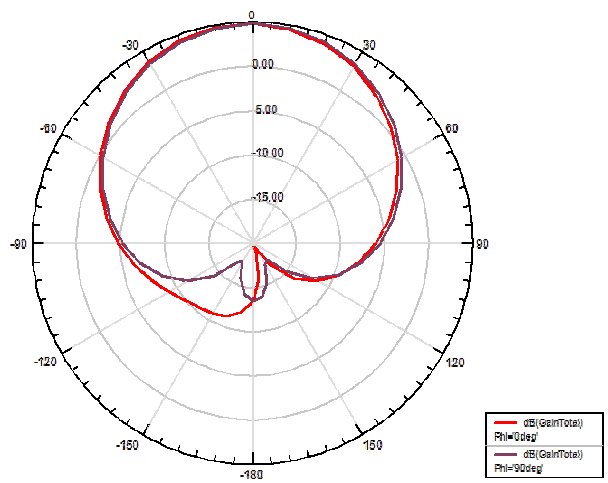
Index

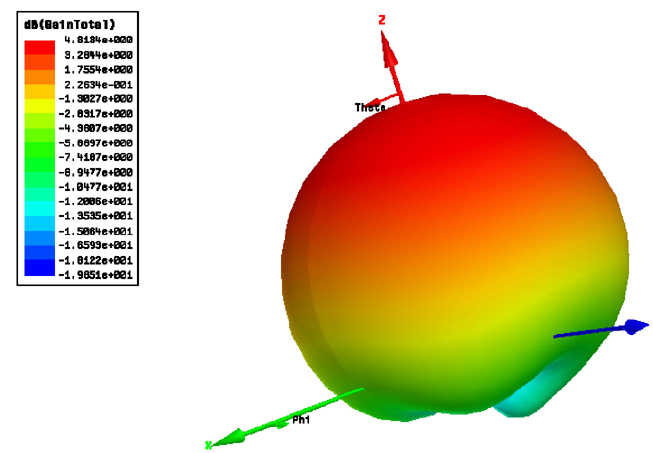


Application: Planar antenna



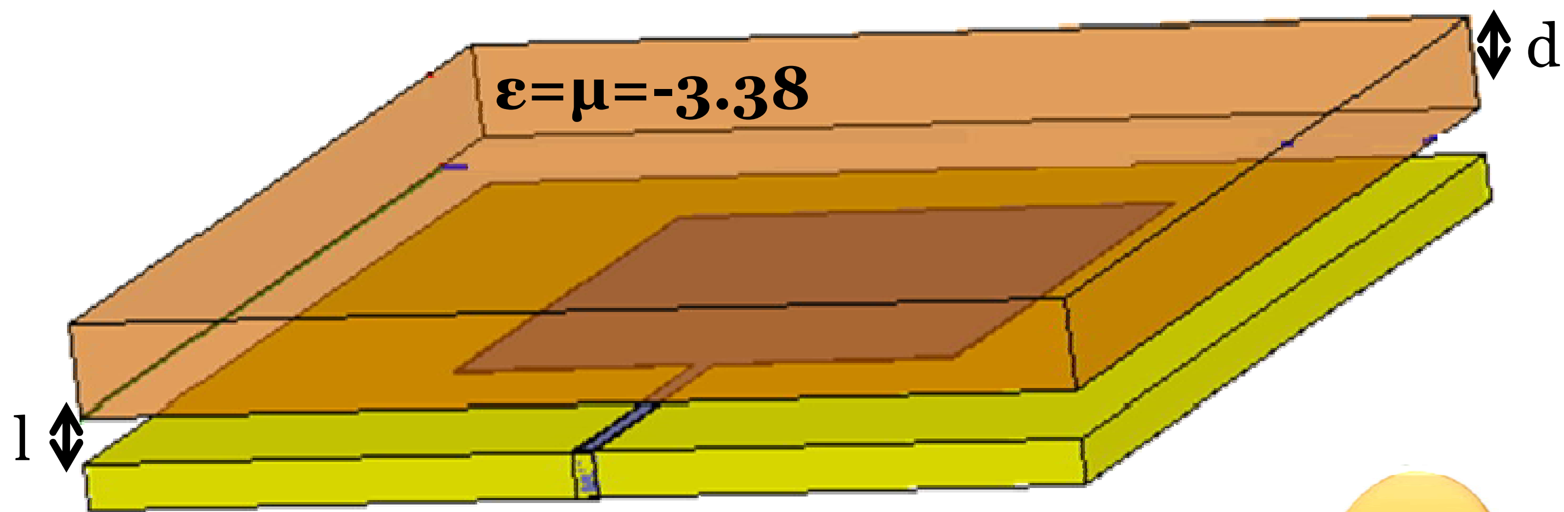






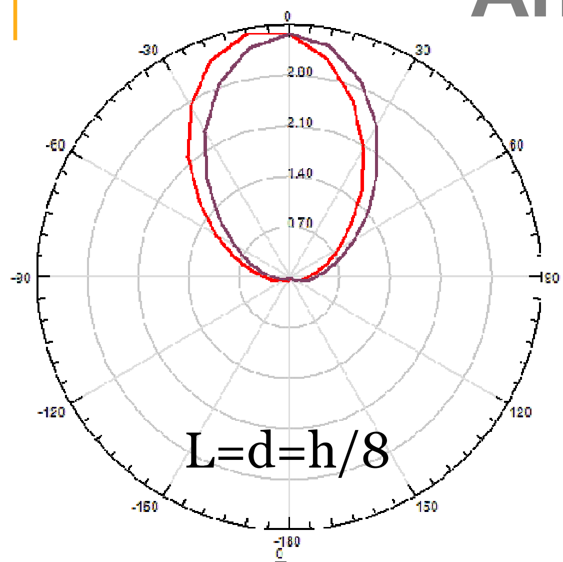
Application: Planar antenna

Used the negative index metamatrial above the antenna
(without losses)

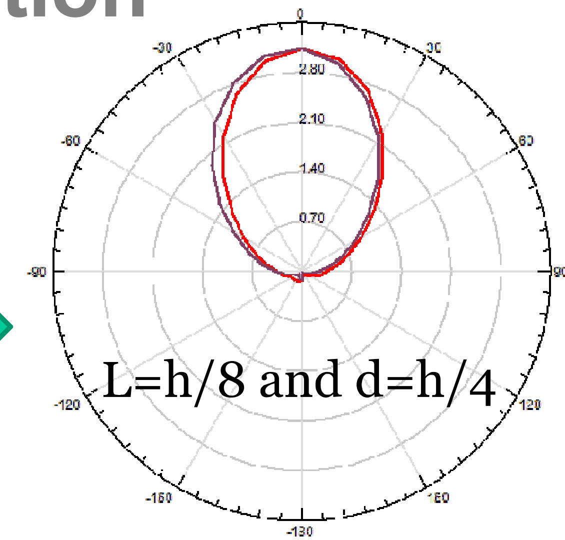


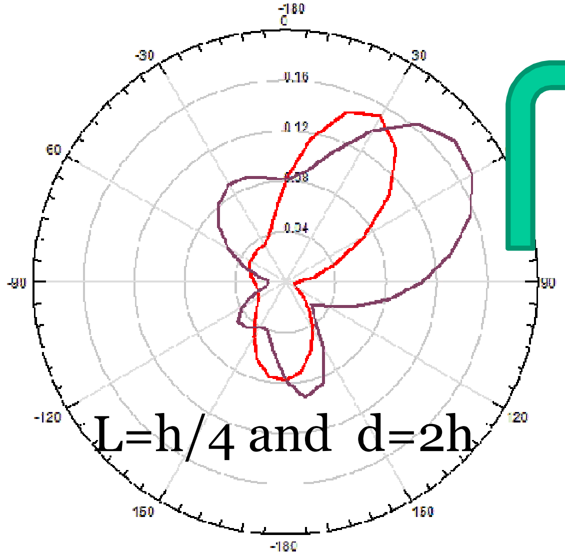
Paramters
« d » and « l »

Antenna Radiation Patterns



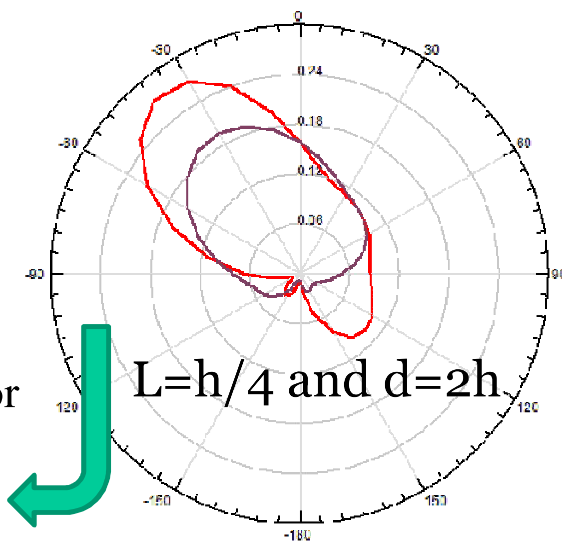
Directivity for d and l are close





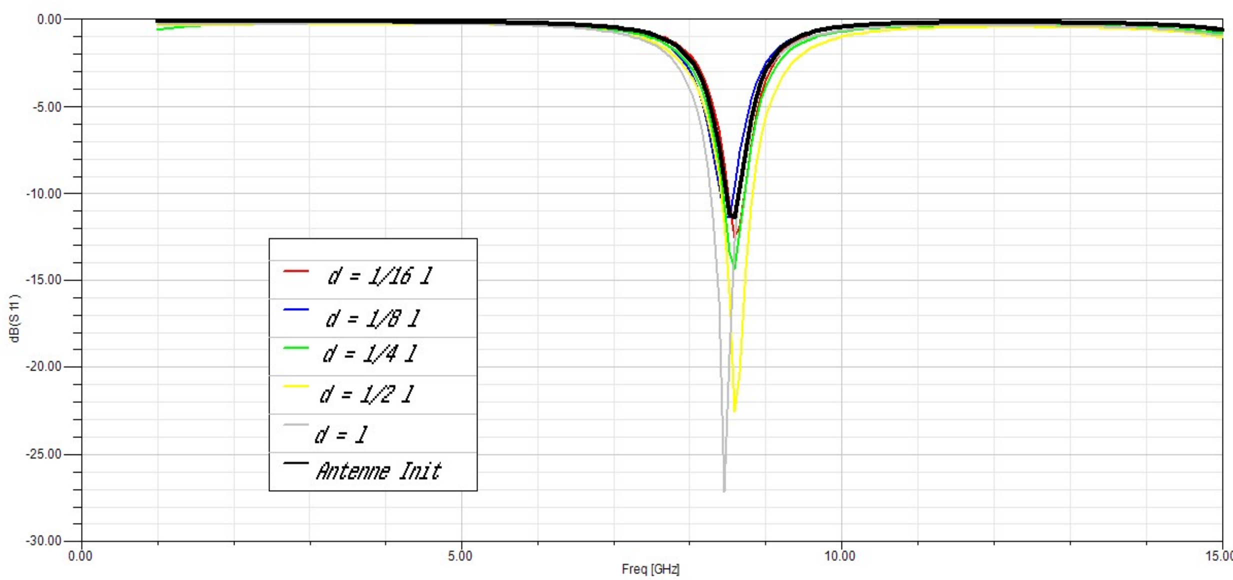
Not directional antenna

Change of directivity for L=d/2



Application: Planar antenna

Adaptation of anetenna (–27 dB) the resonation frequency is 8.5 GHz (for l=d=2h)



➔ **Directional antenna**

➔ The gain is higher

Structure of artificial material with high permeability

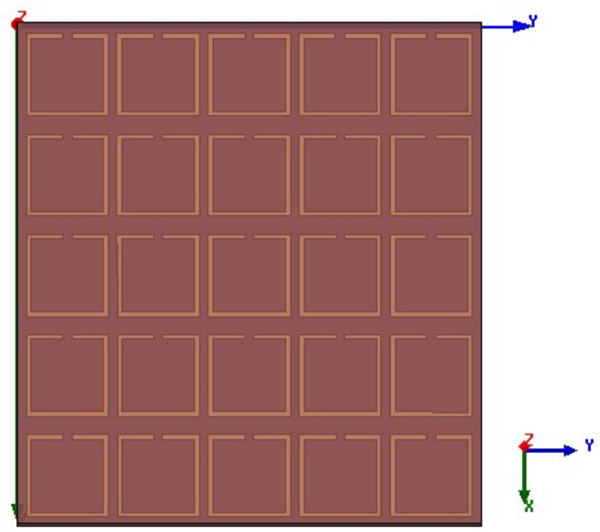
A periodic artificial material characterized by a magnetic resonance without the presence of the magnetic component:

→ a succession of cells.
→ the unit cell dimensioned for the waveband [5 GHz; 15 GHz] and composed of:

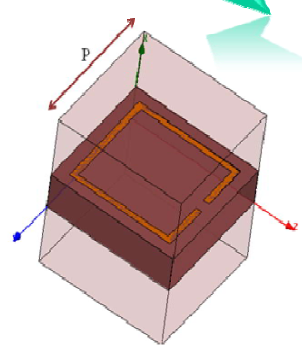
- a Rogers RO4003 substrate with a permittivity equal to 3.38 and height equal to 0.81 mm
- a copper planar element: one square or two squares

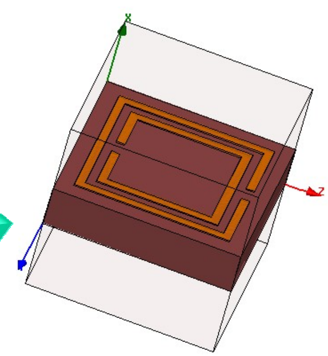
→ **Split-Ring Resonator (SRR)**

Structure of artificial material with high permeability

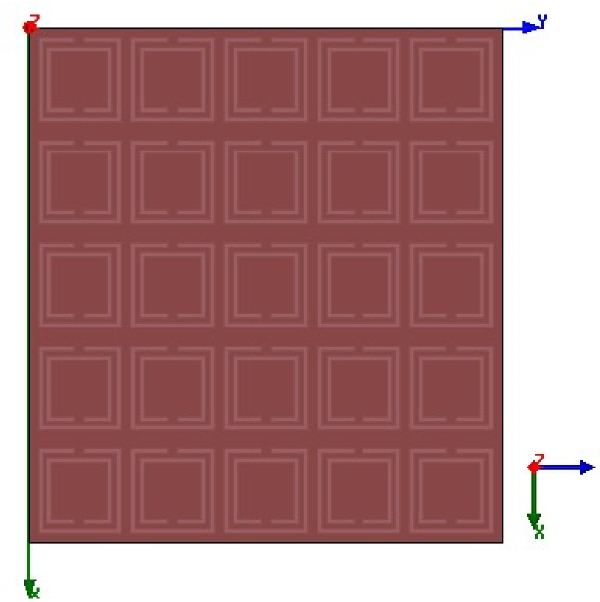


SRR with a square



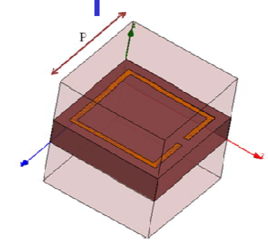


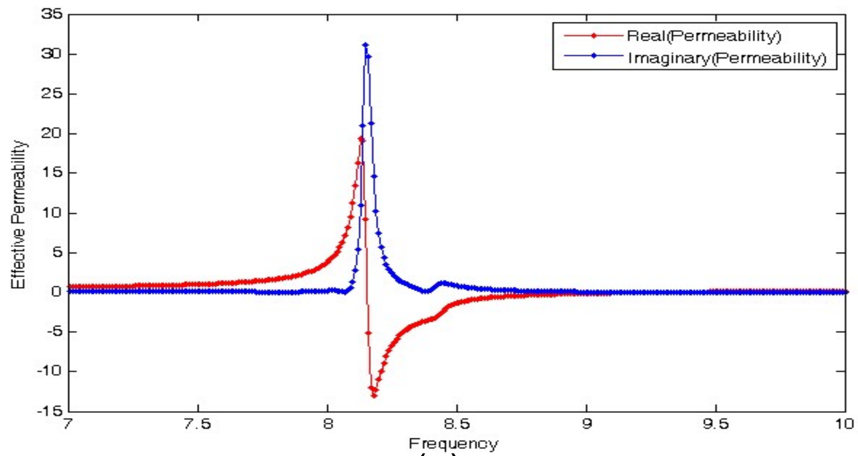
SRR with two squares



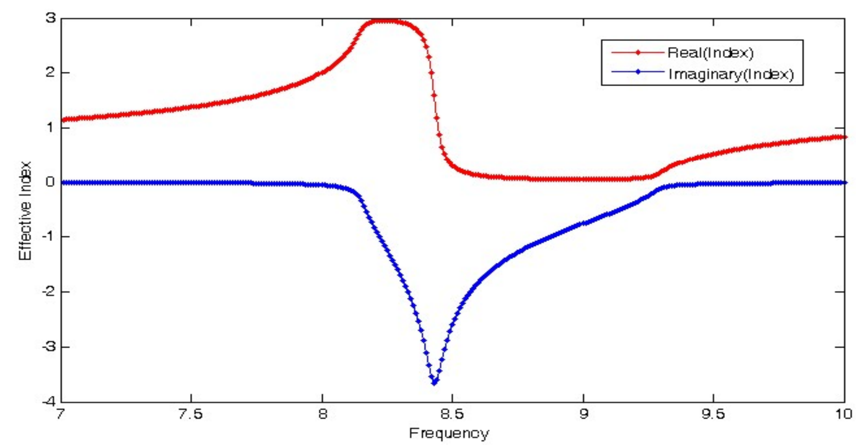
Structure of artificial material with high permeability

Effective parameters characterizing the artificial material





(a)

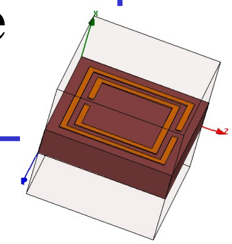


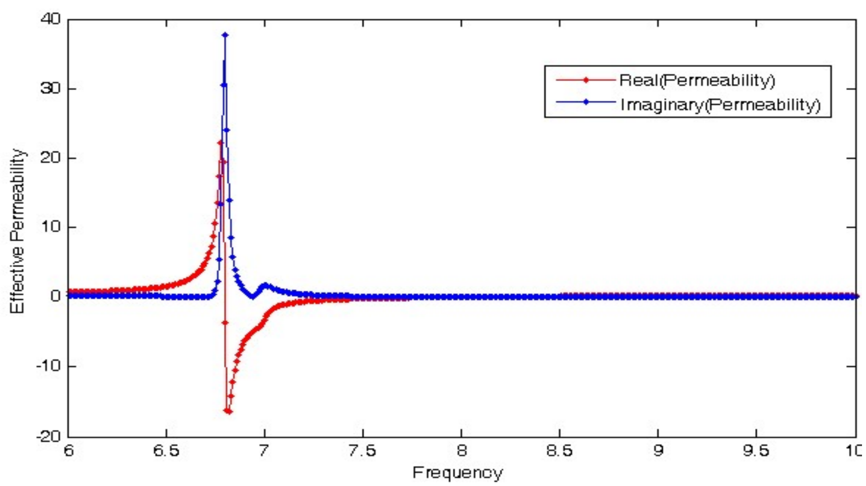
(b)

Effective parameters of SRR with one square resulting from the procedure of homogenization: (a) Effective Permeability (μ_{eff}) ; (b) Effective Index (n_{eff})

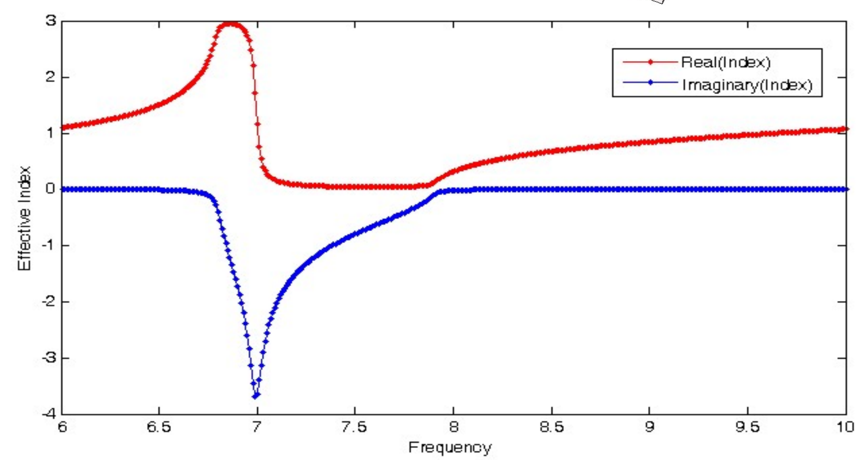
Structure of artificial material with high permeability

Effective parameters characterizing the artificial material





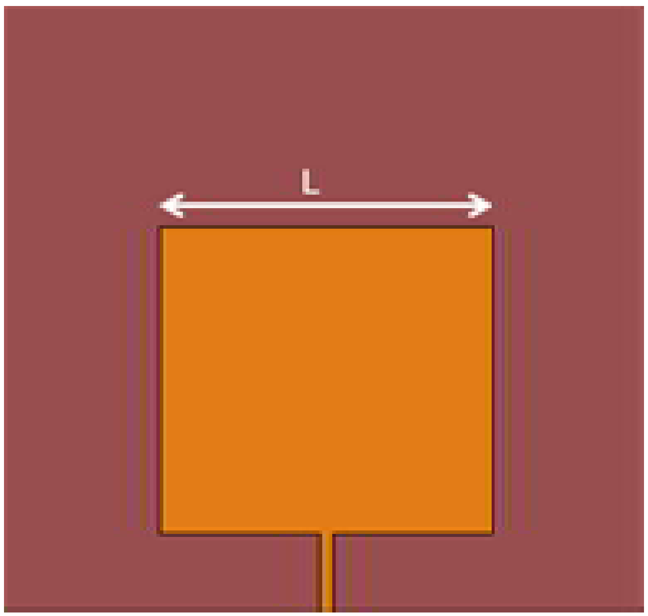
(a)



(b)

Effective parameters of SRR with two squares resulting from the procedure of homogenization: (a) Effective Permeability (μ_{eff}) ; (b) Effective Index (n_{eff})

Application: Miniaturization of a planar antenna

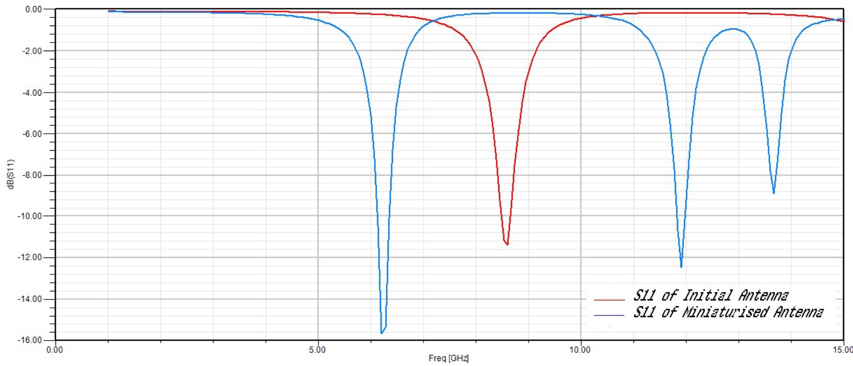


- Square patch of length L
- Substrate: Rogers RO4003
  - h=0.81mm
  - $\varepsilon r = 3.38$
  - $tg\delta = 0.0027$
- Ground plane: a perfect electric conductor (PEC)

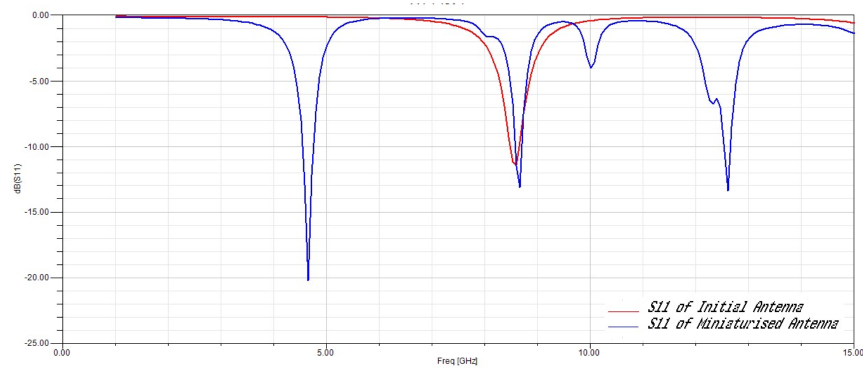
$$L = \frac{\lambda}{2} = \frac{\lambda_0}{2\sqrt{\varepsilon\mu}} \propto \frac{1}{\sqrt{\varepsilon\mu}} = \frac{1}{n}$$

$\mu \nearrow \Longrightarrow L \searrow$

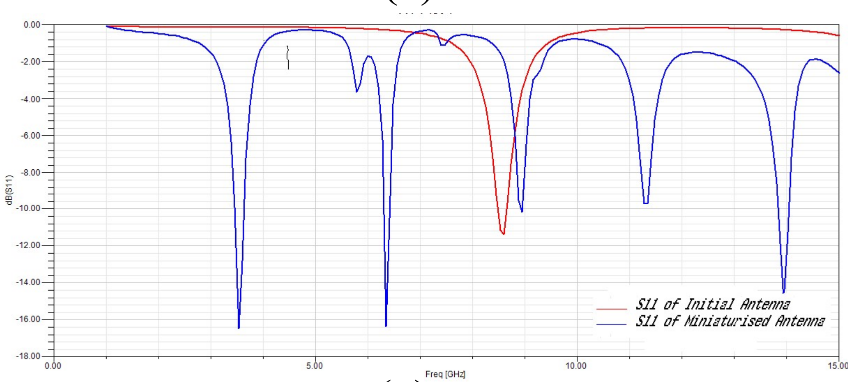
Application: Miniaturization of a planar antenna



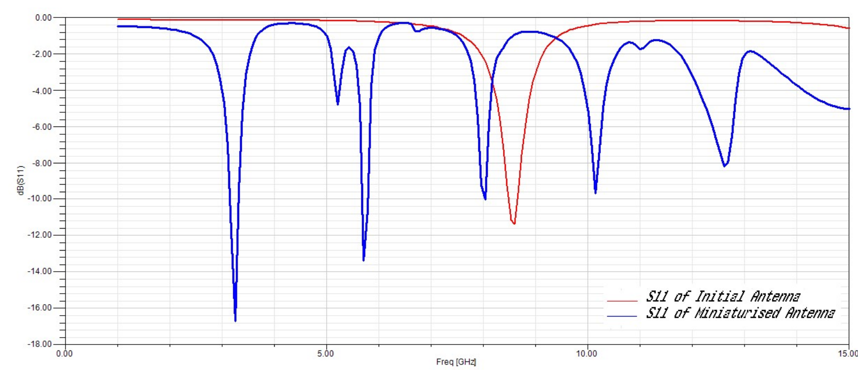
(a)



(b)



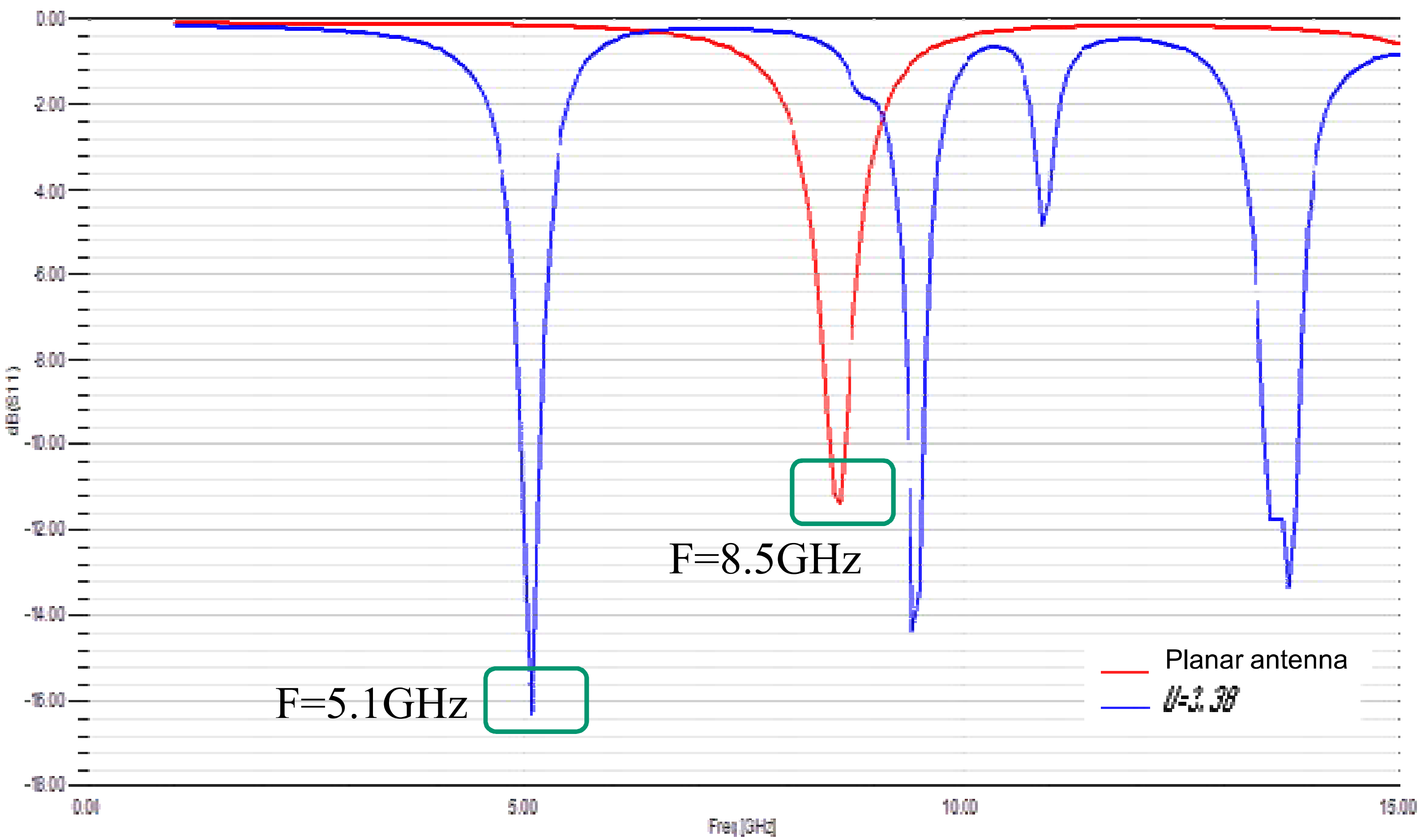
(c)



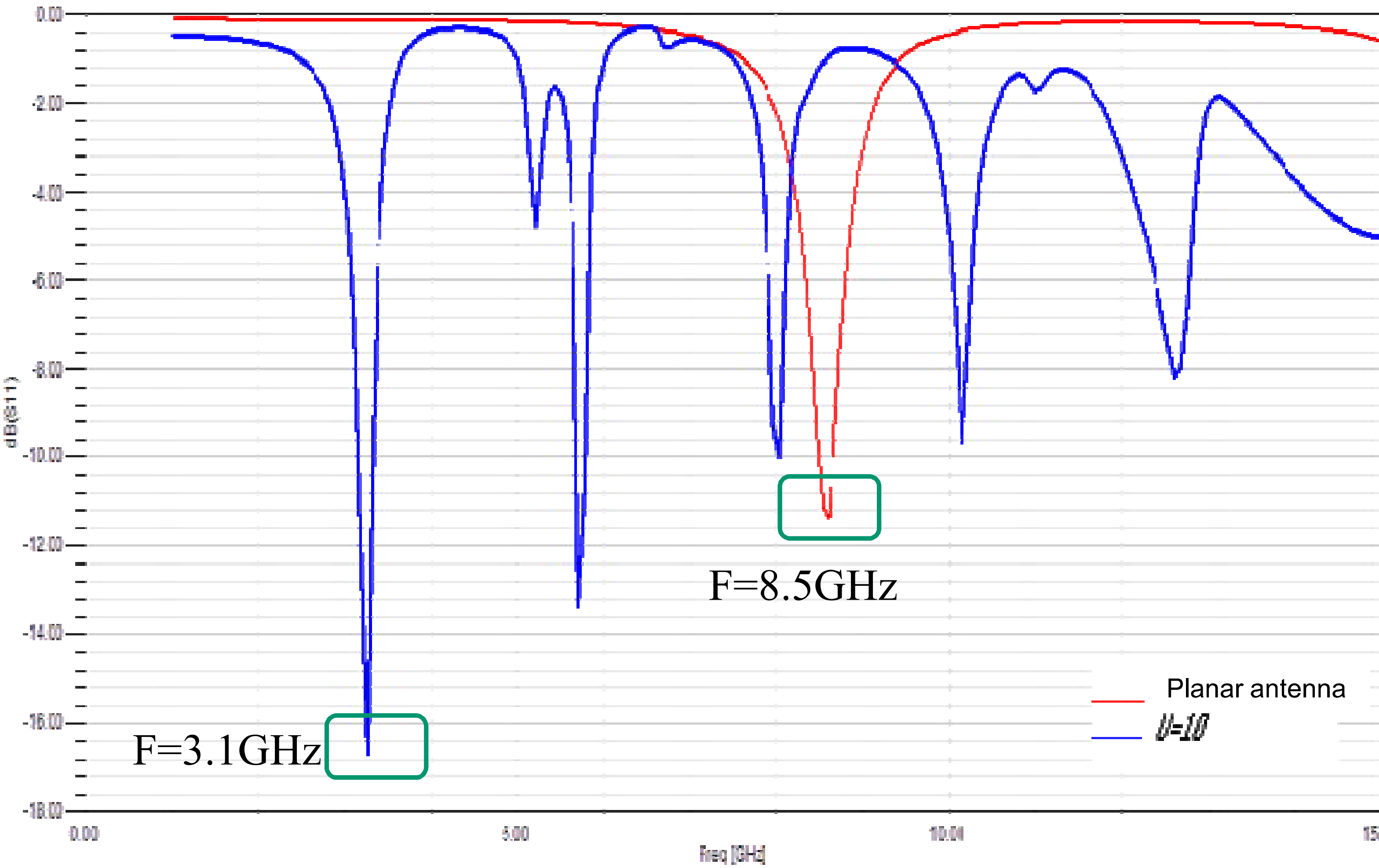
(d)

The reflection coefficient S11 for: $\varepsilon=3.38$: (a) $\mu=2$; (b) $\mu=4$; (c) $\mu=8$; (d) $\mu=10$

Application: Miniaturization of a planar antenna



Application: Miniaturization of a planar antenna



Conclusions

The SRR associated to straight wires are used to obtain a negative index. Also for a particularly bandwidth, the SRR admits high permeability value.

In this work, we used an artificial material in order to ameliorate the planar antenna performances. Then, we determined the effective parameters for an elementary cell based on the homogenization procedure.

Using the metamaterial with negative index above the planar antenna, we obtain for some parameters a directional antenna.

Using the periodic artificial materials, composed of elementary cells, the planar antenna are miniaturized. The artificial material was used as a substrate.

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